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Growth of transplanted *Laminaria japonica* ARESCHOUG in Tokyo Bay far from its natural habitat

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Laminaria japonica transplanted from Hokkaido for cultivation in the western part of Tokyo Bay was studied for growth rate and maturation. Eighty-one plants 50–230 cm in blade length were tagged and studied for a 14-week period from 16 January to 23 April 1982. The blades of nine plants were cut back to 10 cm in length. Growth was determined using the punching method. Blade length and width were measured, surface water temperature was recorded, and water samples were collected for NO_3^--, NO_2^-- and NH_4^+-N analyses. The blades increased an average of 4.5 cm/day in length and 1.2 mm/day in width for the run of the study. The maximum growth rate (5.7 cm/day in length and 3.3 mm/day in width) occurred for a period of 1–10 February and gradually decreased thereafter. The growth rates of the cut plants were always lower than but parallel to those of the uncut plants. Inorganic nitrogen levels in the surface water remained high and were not limiting to growth. The number of plants up to 15 per bunch growing on the cultivation ropes did not affect the growth rate greatly. Eighty-eight percent of the plants produced sori. Sori production did not seem to affect the growth rate.

Key Index Words: Cultivation, growth rate, Laminaria japonica, *maturation, Tokyo Bay, transplantation.*

Laminaria japonica ARESCHOUG is one of the valuable seaweed crops in Japan and China (TSENG 1981a). A new cultivation technique was developed over 15 years ago (HASEGAWA 1971) which increased greatly the harvest of this seaweed (KAWASHIMA 1984). The new techniques have been applied to the transplantation and cultivation of *L. japonica* in areas outside its natural habitat in order to increase production. One of these areas is Otsu Bay off Yasuura, Kanagawa Pref., on the western shore of Tokyo Bay. The area is situated about 500 km south from the southern limit of *L. japonica*'s natural habitat. We attempted to study the growth of this transplanted population in the nutrient rich Tokyo Bay.

Material and Methods

From 16 January to 23 April 1982, nine samplings were made of the *Laminaria japonica* plants at the Yokosuka City Fisheries Co-op, Yasuura cultivation ground in Otsu Bay (35° 16′ N, 139° 42′ E) in the western part of Tokyo Bay (Fig. 1). The plants used in this study originated from seed strings transported from the Ishizaki Fisheries Co-op in Hakodate, Hokkaido. A total of 81 *L. japonica* plants were tagged, nine of which were cut back to 10 cm in blade length to observe the effects of cutting on growth. The plastic tags were numbered and attached to the stipe of each plant with thin, plasticized wire. When tagged between 16 January and 10 February, the plants ranged from 50 to 230 cm in blade length. The length of the blade and the width at the widest point were measured for each plant at each sampling trip.

Growth was measured using the punching method developed by PARK (1948),

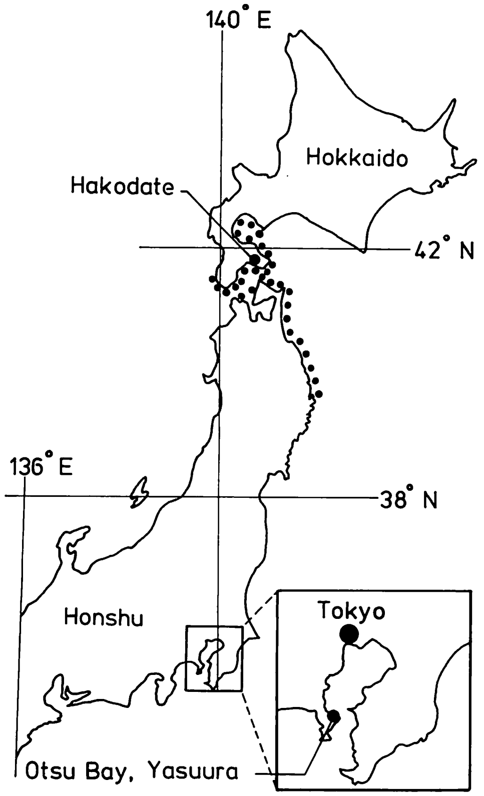

Fig. 1. The location of the study site in Tokyo Bay. Natural range of *Laminaria japonica* is indicated by dots along the coast of northern Japan.

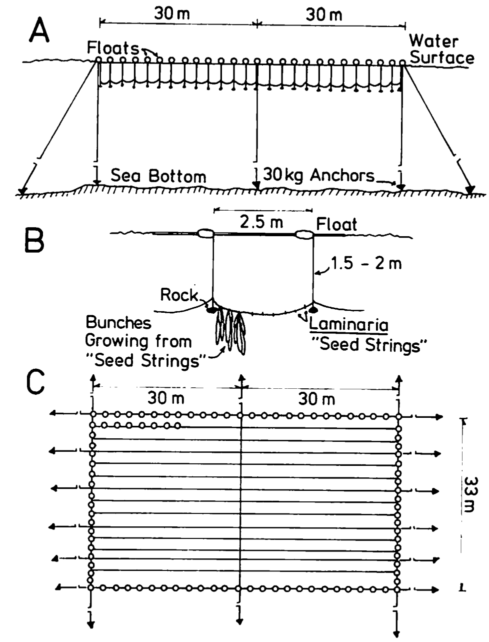

Fig. 2. The cultivation apparatus for *Laminaria japonica* at Yasuura. A. Side view. B. Close-up of the upper portion of side view. C. Overview.

as has been used for *Laminaria* spp. by many researchers (Anderson *et al.* 1981, Chapman and Craigie 1977, Chapman and Lindley 1980, Gagne and Mann 1981, Kain 1979, Sasaki 1973). This required punching a small hole in the blade along the median line above the stipe-blade junction where the zone of new growth is located. The growth (elongation) rate (cm/day) was determined from the distance the punch moved away from the stipe-blade junction as the blade grew. Each plant was punched 20 cm above the stipe-blade junction during each measurement. Forty-five plants were used for determining increases in length and growth rates. The presence of sori was recorded. Surface water temperature was also recorded. Surface water samples were collected and carried back to the laboratory in plastic bottles on ice. Upon return to the laboratory, the samples were Millipore (HA) filtered and frozen for later NO_3^--, NO_2^-- and NH_4^+-N analyses using the methods of Strickland and Parsons (1968).

Results

Of the 81 plants tagged from 16 January to 10 February 1982, only 60% remained by the end of the study on 23 April 1982. Loss was mostly due to handling. The tags sometimes weakened the stipes which would then break during measurement. Sometimes the tags would slip down and off the blades. Kain (1975) also reported problems with tagging her plants and found that nylon tape worked best.

The increase in the total blade length over time and the growth rate calculated from the blade lengths are shown in Figs. 3 and 4, respectively. As can be seen in Fig. 3, the blade length increased linearly to reach a maximum of 420 cm on 16

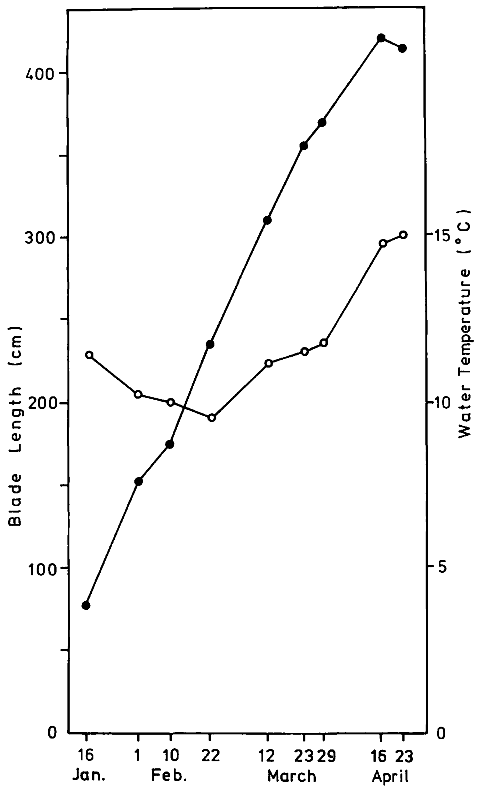

Fig. 3. Growth (average blade length) of *Laminaria japonica* (solid circle) and surface water temperature (open circle) of the Yasuura cultivation ground in Tokyo Bay from 1c January to 23 April 1982.

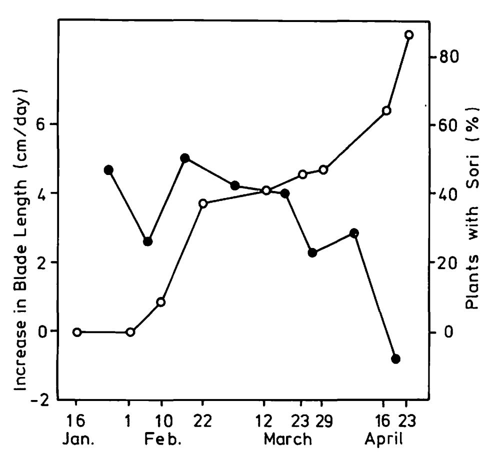

Fig. 4. Average rate of increase in blade length (solid circle) and the percentage of total number of plants with soral development (open circle) for *Laminaria japonica* in Tokyo Bay from 16 January to 23 April 1982.

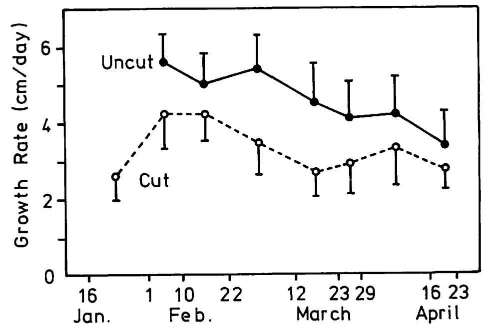

Fig. 5. Average growth rates in blade length with standard deviation for uncut (solid circle) and cut (open circle) *Laminaria japonica* in Tokyo Bay from 16 January (cut) or 1 February (uncut) to 23 April 1982.

April, after which there was a decrease in length. The cm/day increase in length was rather erratic with a high of 5.0 cm/day for a period from 10–22 February and a low of −0.8 cm/day for a period of 16–23 April (Fig. 4). The growth rates determined by the punching method are shown in Fig. 5. The rates of the punching method are higher than those of total blade length. As can be seen in Fig. 5, the average growth rate of uncut plants decreased over time starting with a high of 5.7 cm/day for a period of 1–10 February to a low of 3.3 cm/day for a period from 16–23 April. The average rate obtained by the punching method for all uncut plants over the study period was 4.5 cm/day compared to a value of 3.6 cm/day on the increase in total blade length. The greater reliability of the punching method is apparent from these figures. There was also great individual variation in growth rates. Individual rates varied from 1.5 to 7.4 cm/day with individual plant, and the average over the study period varied from 2.7 to 6.0 cm/day.

Fig. 6 shows changes in the average increase of blade width with time. Plants attained an average of 10 cm in width and the average rate of increase in width over the study period was about 1.2 mm/day; the heighest average rate of increase was 3.3 mm/day for a period from 16 January–

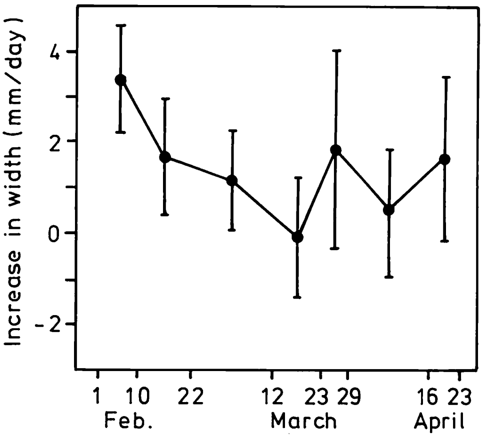

Fig. 6. Average rate of increase in width with standard deviation for *Laminaria japonica* in Tokyo Bay from 1 February to 23 April 1982.

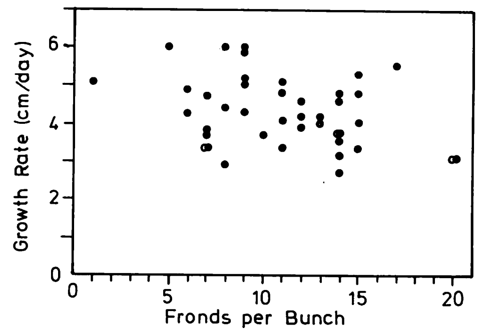

Fig. 7. Comparison of the growth rate of *Laminaria japonica* to the number of plants in each bunch growing on cultivation ropes in Tokyo Bay (refer to Fig. 2). Each point represents the average growth rate over the experimental run for each plant for the study period.

10 February and the lowest, −0.1 mm/day for a period from 12–23 March. Again there was great individual variation. The greatest individual average increase over the study period was 2.1 mm/day and the lowest 0.5 mm/day.

The average growth rate of the plants which had been cut back to 10 cm in blade length is shown in Fig. 5 along with the average for the uncut plants. The average rate of cut plants increased at first but then decreased with time. The average for the study period was 3.5 cm/day which is less than that of the uncut plants. The average rate for the cut plants was always lower than but parallel to that of the uncut plants. By 23 April the cut plants had only grown to an average of 3 m in length compared to 4.1 m for the uncut plants. Fertility occurred in some of the cut plants but only by 23 April.

By the end of the present study, almost 90% of the uncut plants had produced sori. Fig. 4 shows the time course of soral development. There was a sudden increase in the percentage of fertility around the middle of February; with a slow development during March plants with sori increased to reach a maximum of 88% at the end of the study. The blade length did not seem to be a determining factor for fertility. Some of the plants in the study produced sori at a frond length of only 1.5 m while others reached a length of 4 or 5 m before any sori were produced. The plants in the present study had a fairly large amount of epiphytes, and particularly bryozoa, growing on the blade surface.

There were 1 to 20 plants per bunch (cf. Fig. 2, B) in the present study. They were used to examine the effect of crowding and shading on the plants on the cultivation ropes. The average growth rate of individual plants for the study period was plotted against the number of plants per bunch (Fig. 7). There only seems to be a trend of slight decrease in the growth rate with increase in the number of plants per bunch. However, the number of samples over 15 plants per bunch is too small to draw any conclusions from.

The surface water temperature in the cultivation field varied from a low of 9.7°C on 22 February to a high of 15°C on 23 April (Fig. 3). Inorganic nitrogen (nitrate, nitrite, ammonium and total nitrogen) concentrations in the surface water of the cultivation field are shown in Fig. 8. The levels of nitrate and ammonium nitrogen and, consequently of the total inorganic nitrogen, were consistently high with total values varying from 26

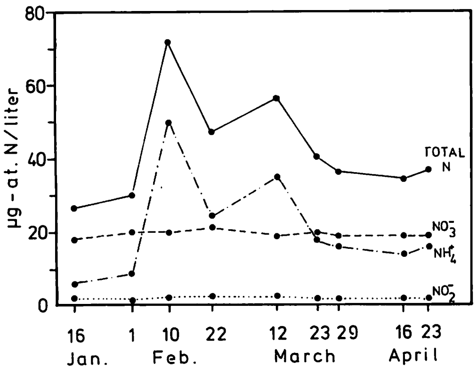

Fig. 8. Inorganic nitrogen concentration in the surface water of the Yasuura cultivation ground in Tokyo Bay from 16 January to 23 April 1982. Total N is the sum of NO_3^--N and NH_4^+-N.

to 72 μg-at. N/*l*. Nitrate and nitrite nitrogen concentrations remained fairly constant while the ammonium nitrogen concentrations varied greatly during the study period. Variations in the total inorganic nitrogen concentration were apparently dependent on the ammonium nitrogen concentration.

Discussion

Laminaria japonica ("Ma-kombu") is one of the major seaweeds harvested in Japan. More than 15 years ago, in order to stabilize and increase production of this valuable seaweed, a new cultivation technique was developed by HASEGAWA (1971) in Hokkaido, the northernmost island of Japan and the main *Laminaria* cultivation district. This technique, as known as "Forced Cultivation", produces commercial quality "Ma-kombu" in one year instead of the two years required for natural *L. japonica* to reach the same quality. KAWASHIMA (1984) gives description of this technique precisely.

At Yasuura, the seed strings of *L. japonica* used for cultivation are transported from Hokkaido. The sporophytes are placed in the field by mid-December when the water temperature falls down below 18°C. The water temperature in Tokyo Bay off Yasuura is above 18°C for about six months of the year. This limits the cultivation time of *L. japonica* to about five months from mid-December to the end of May in this area. At Yasuura, however, the harvest of cultivated *L. japonica* is at the end of April, a month before the natural conditions would be limiting to growth. The reason for this early harvest is that the fishermen must dismantle the cultivation apparatus and devote their time to other fisheries. During the course of the present study, the water temperature varied only from about 5 to 15°C (Fig. 3) and remained within the levels suitable for the growth of *Laminaria* (KAWASHIMA 1984). At Yasuura, the highest growth rate was seen at around 10°C (Figs. 3 and 5). In Korea, the best growth rate was seen around 12°C for *L. japonica* (BAIK and PYEN 1973).

During the course of the present study the total inorganic nitrogen concentration in the surface water at the cultivation ground remained high as shown in Fig. 8. Though there were some variations in inorganic nitrogen concentrations, even in the short term, during the period of study, the levels never fell to concentrations that would be limiting to growth of *L. japonica*.

The first experiment in transplanting *L. japonica* outside its natural habitat was in 1966 in the Seto Inland Sea off Hyogo Pref. west of Osaka (II *et al.* 1966). Other experiments in transplanting *L. japonica* were also attempted in Ariake Sea off Nagasaki Pref. (YOTUI and NISHIKAWA 1968) and in a sea area of Sado Island, Niigata Pref. (SAKAI 1968). The techniques and the principles of cultivation are basically the same for the Yasuura plants. During a 4.5 month cultivation period at Yasuura, the plants grew to blade length of 4 to 6 m. The average length for Hyogo plants was only 2.5 m over a five month cultivation period (II 1967).

Growth rates in *Laminaria* species have been investigated by many researchers. As to the maximum growth rate were reported 8.15 cm/day for *L. angustata* (HASEGAWA 1962), 6.8 cm/day for *L. angustata* var. *longissima* (SASAKI 1973), and 4.5 cm/day (HASEGAWA 1967), 3.45 cm/day (BAIK and PYEN 1973) and 3.6 cm/day (FUNANO and ISHIKAWA 1974) for *L. japonica*. Such conditions as water temperature and available nutrients were possibly not the same for these populations which could account for the different rates. There could also be specific and genetic differences between the populations. In addition, methods of growth measurement were not the same in these investigations. It would therefore seem to be difficult to compare growth rates of plants reported from different areas even if they are of the same species.

The interesting point is the great individual variation found in the growth rates (Fig. 5) of Yasuura plants which all came from the same stock in Hokkaido and were subjected to the same conditions. INDERGAAD and JENSEN (1981) also found very pronounced individual variation in the growth rate of seemingly identical plants of *L. digitata*. They suggested that this variation can be used to improve the cultivation of *Laminaria* by selecting the best and fastest growing plants for use as genetic stock. DRUEHL and BOAL (1981) also suggested genetic control to improve product quality and uniformity by producing superior clones. Workers in China have used inbreeding and selection of superior *L. japonica* to produce stocks of plants with desirable qualities (e.g. high iodine content) for use in cultivation (TSENG 1981b). Through experimentation it should be possible to choose plants superior in growth and quality which could be maintained as gametophyte stock cultures for use in producing plants for cultivation.

The decrease in growth rate of the Yasuura plants with time (Fig. 5) is rather difficult to explain. It is doubtful that the inorganic nitrogen concentration was responsible. During the present study, inorganic nitrogen levels never decreased enough to affect the growth of *L. japonica*. Perhaps the 5°C increase in water temperature influenced the decrease of growth rate of the Yasuura plants with time. Another possible factor influencing the growth rate is plant age. SASAKI (1973) reported that in *L. angustata* var. *longissima* second and third year blades increased in length faster than first and second year blades. All the plants at Yasuura were, at the most, eight months old by the time of harvest, not enough time to pass through even one yearly variation. To check if there was a possible relationship between plant age (roughly corresponding to length) and growth rate, a graph was made of these two factors (Fig. 9). This figure takes the individual growth rates of all the uncut plants used for determining the average growth rates in Fig. 5 and plots the rates in 50 cm blocks (based on total blade length) as the plants grew. There seems to be an increase in growth rate from below 50 cm in blade length to reach a peak at 100–150 cm in length with a decrease thereafter. Since most of the plants were 100 cm and over in blade length when the growth rates were determined (Fig. 3), it is said that the decrease in the average growth rate is superficially related to the length (or roughly age) of the plant. However, only from these results, it is difficult to deduce specific relationship of the growth rate to water temperature and/or plant age.

Irregular change in the rate of increase

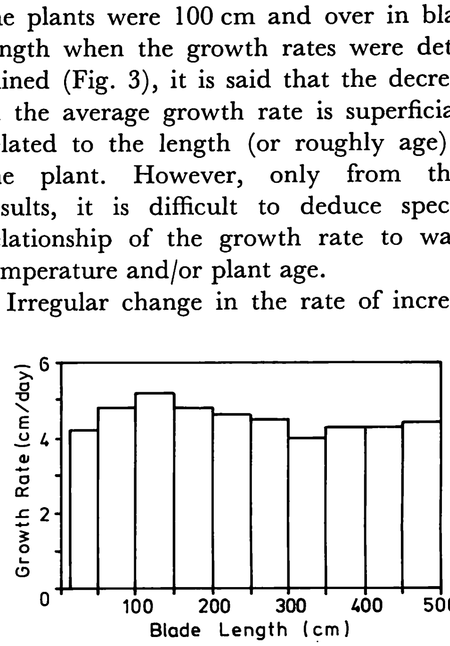

Fig. 9. Relationship of growth rate to blade length of *Laminaria japonica* cultivated in Tokyo Bay.

in width is also difficult to explain, particularly the negative value of growth rate for a period from 12–23 March (Fig. 6). Such decreases in width are possible and have been reported to be related to the time of year in *L. saccharina* (PARK, 1948). FUNANO and ISHIKAWA (1974) also reported the decrease in blade width of *L. japonica*.

KAIN (1975) reported that the presence of epiphytes on the blade inhibited soral development somewhat. Perhaps the fertility rate at Yasuura would have been higher than 88% had the epiphyte and bryozoa coverage been less. The development of sori on a plant did not seem to affect the growth rate of the plant (Fig. 10).

In commercial cultivation of *Laminaria*, seed strings 5 cm long, on which young sporophytes are growing, are inserted at regular intervals into the cultivation ropes in the field. Numerous plants grow out from each length of seed string, forming bunches of plants (Fig. 2, B). Excess plants are cut away by the fishermen in order to improve light exposure for those plants remaining. In Hokkaido, where most of the *Laminaria* cultivation is carried out, only 5 plants are left per bunch (KAWASHIMA 1984). In the present study, however, the relationship of the average growth rate to the number of plants per bunch could not be clear within the range of 1–20 plants per bunch (Fig. 7).

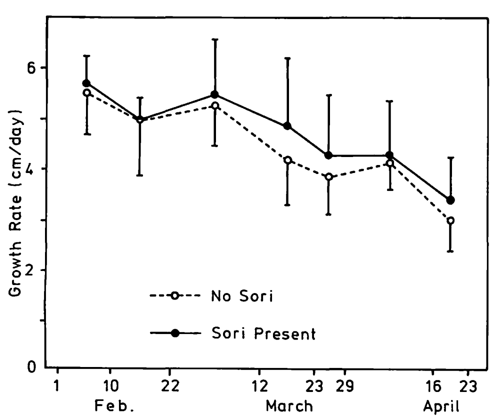

Fig. 10. Comparison of average growth rates with standard deviation for fertile (solid circle) and unfertile (open circle) *Laminaria japonica* cultivated in Tokyo Bay from 16 January to 23 April 1982.

While the plants which had been cut back to ten cm recovered, grew and even became mature, the growth rates and lengths were always less than those of the uncut plants (Fig. 5). This is counterproductive to cultivation purposes. In China, however, they practice what they call the "tip-cutting method" where as much as one-third of the *Laminaria* blade is cut away (TSENG 1981b). TSENG (1981b) reported that cutting the blade at certain intervals improved the growth conditions and product quality by improving the light conditions of the fronds and water movement around them.

The *L. japonica* population at Yasuura is unique in many ways, as a transplant outside its natural area of distribution and as an experiment in aquaculture. The plants are able to grow and progress through maturity. Unfortunately for aquaculture purposes, the quality is not as good as the Hokkaido plants. Commercial quality of *L. japonica* is mainly valued for its thickness; the Yasuura plants are relatively thin and "tender". This word was used by a person at Yokosuka City Fisheries Co-op to describe the quality of the *Laminaria* plants produced in the district. Apparently, this tender and delicious (quoting the Co-op member) *L. japonica* is distributed in Kanagawa Pref. and has become popular in five to six years since *L. japonica* cultivation began at Yasuura. In 1981, 12 tons (dry weight) of *L. japonica* were harvested and sold through the Co-op, however, it was only about 0.1% of the total yield of cultivated *Laminaria* in Japan.

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キャスリーン C. トーコ・庵谷　晃・有賀祐勝・岩本康三：東京湾における養殖マコンブの生長

東京湾の一部では近年冬一春季のマコンブ養殖が定着してきたが，その生長や成熟についての知見は少ない。横須賀市東部漁協が函館市石崎漁協から移入し地先の施設で養殖したマコンブ81個体について1982年 1 月16日か

ら４月23日まで観察したところ，通期全個体についての平均生長速度は葉長で 4.5 cm/日，葉幅で 1.2 mm/日であった。観察開始時に葉状部 10 cm を残し切断した個体の生長は普通個体より常に下まわり，収穫時（４月末）には普通個体の平均葉長 4.5 m に対し 3.0 m にとどまった。収穫時にはおよそ90%の個体に子嚢斑が形成された。子嚢斑形成と生長速度には関連はなかった。（108 東京都港区港南４丁目５番７号 東京水産大学水産植物学教室）